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2. Patent application number *(The Patent Office will fill in this part)* — 0314747.7 — 25 JUN 2003

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

   AEA Technology plc
   329 Harwell
   Didcot
   Oxfordshire OX11 0QJ

   Patents ADP number *(if you know it)* — 696937 2001

   If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention — Detecting failures in flexible multistrand steel structures

5. Name of your agent *(if you have one)*

   "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

   Peter Turquand MANSFIELD
   Accentus plc
   Patents Dept
   329 Harwell
   Didcot
   Oxfordshire OX11 0QJ

   81322243001

   Patents ADP number *(if you know it)*

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

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Number of earlier application	Date of filing *(day / month / year)*

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Request for preliminary examination and search *(Patents Form 9/77)*	1
Request for substantive examination *(Patents Form 10/77)*	
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11. Peter Turquand MANSFIELD (on behalf of AEA Technology plc by virtue of a Power of Attorney dated 18th February 2003)

I/We request the grant of a patent on the basis of this application.

Signature — Date 24/6/03

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Frances Esplin – 01235 43 2037

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Fig. 1

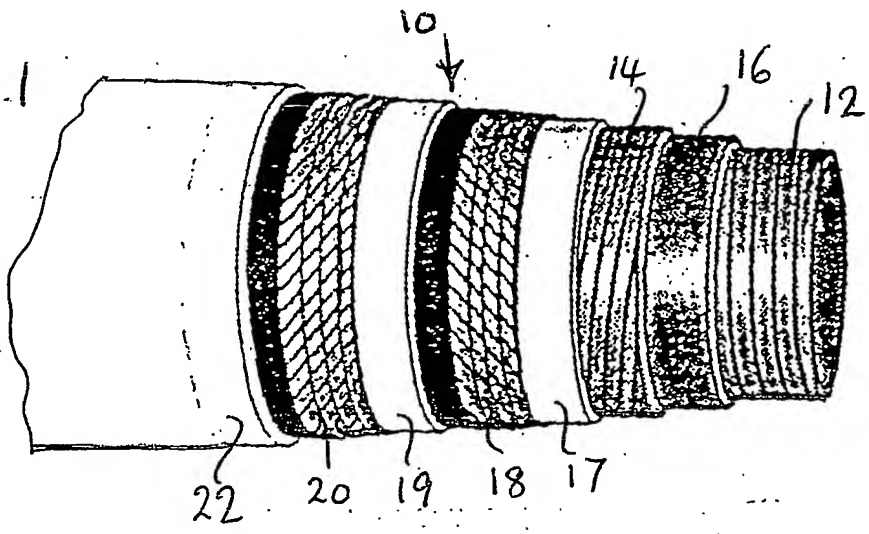
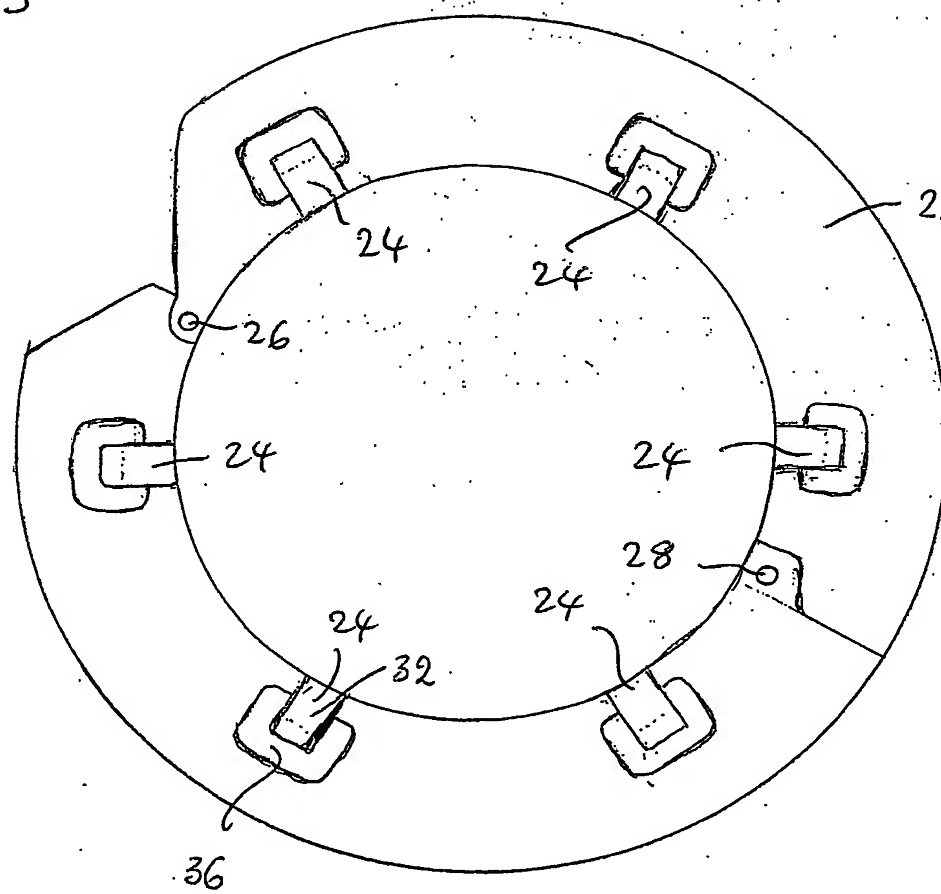


Fig. 2



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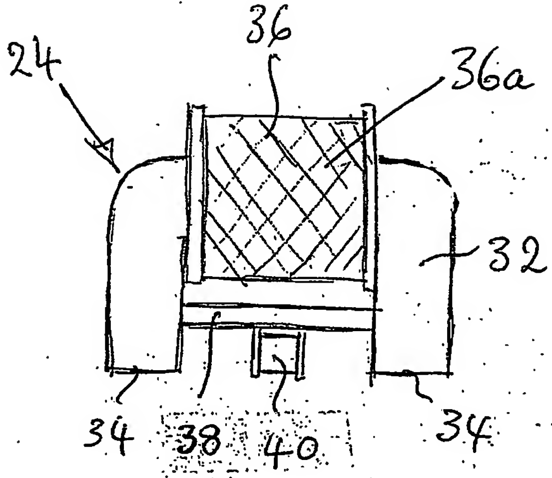
Chartered Patent Agent
Agent for the Applicants

Fig. 3



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MdCm

Detecting Failures in Flexible Multistrand Steel Structures

This invention relates to a method and apparatus for monitoring flexible multistrand steel structures such as cables or risers, for detecting failures.

Flexible risers are used to connect oil and gas wells to floating production platforms, the flexible riser being a steel-wire-reinforced flexible hose. Typically such a riser is connected to a turret on the floating platform, the turret providing some degree of rotation, and the flexible riser is typically hundreds of metres long. Failure in such a flexible riser can lead to significant quantities of oil leaking into the environment. It has been found that such risers typically fail close to the point at which the riser is connected to the turret, this failure being due to the fatigue loading endured by the riser at the point where the forces are greatest due to wave motion and rotation of the floating platform. This failure mode is recognised, but there exists no technology capable of inspection of such risers to warn of catastrophic failure, particularly with the flexible riser in situ connected to the turret and carrying a product.

According to the present invention there is provided a method for monitoring a flexible elongate structure comprising at least one layer of steel wires near the surface, the steel wires extending at least partly along the length of the structure, the method comprising inducing an alternating magnetic field much less than saturation in the steel wires using an electromagnetic coil, and monitoring the alternating magnetic flux density near the surface of the structure, determining from it a parameter indicative of stress in the steel

wires, and hence detecting if any wires have broken.

Preferably the magnetic field is in a direction substantially parallel to the longitudinal axis of the structure. Measurement might also be taken with a magnetic field in a circumferential direction, and these measurements may be used for normalisation.

Flexible risers include a braided steel wire layer to provide tensile strength near the outer surface of the riser, and may in fact include two such steel wire layers. The failure mode typically involves fatigue fracture of one of the outer steel reinforcing wires or strands. When a wire fails in this way, the remaining intact wires or strands must take the extra load, and therefore their total stress increases. By arranging an array of electromagnetic stress sensing probes around the circumference of the riser the failure of one or more strands will result in a variation of the measured stress around the circumference. An increase in stress in one region indicates the failure of a strand in a nearby region, or at least an impending failure where a fatigue crack has propagated through a significant proportion of the cross-section of a strand or wire.

An alternative sensor arrangement is to use a single coil that encircles the elongate structure, so that changes in stress in all the reinforcing wires are monitored simultaneously. This may be preferable for smaller diameter risers, or for steel ropes and cables. Failure of one or more strands will lower the stresses in the failed strands but increase the stresses in the remaining intact strands, because the overall load is unchanged. However, because of the nonlinearity of the changes in magnetic properties of ferromagnetic materials with stress, the occurrence of such a failure can

nevertheless be detected.

Thus the preferred method utilises an array of electromagnetic stress sensing probes arranged around the circumference of the structure. This enables failure of a strand or wire to be detected, and also provides some spatial resolution as to the location of the failure. Greater resolution can be obtained by using smaller probes, but smaller probes are more affected by lift-off from the surface. A preferred arrangement uses probes that are of diameter between 30 mm and 90 mm, preferably about 60 mm, as such probes are not excessively affected by lift-off and nevertheless provide adequate spatial resolution. The optimum size depends on the size of the riser or cable.

In the preferred stress-measurement method the or each probe comprises an electromagnet means, means to generate an alternating magnetic field in the electromagnet means and consequently in the structure, and a magnetic sensor arranged to sense a magnetic field due to the electromagnet means; and the method comprises resolving signals from the magnetic sensor into an in-phase component and a quadrature component; mapping the in-phase and quadrature components directly into stress and lift-off components; and deducing the stress from the stress component so determined.

The mapping requires a preliminary calibration, with a specimen of the material, to determine how the in-phase and quadrature components of the signal vary with lift-off (at a constant stress) and vary with stress (at a constant lift-off), and deducing from the calibration measurements the applicable mapping for any stress and any lift-off. (In this context, only the variation with lift-off (at constant stress) is actually required.) The

mapping may be represented in the impedance plane (i.e. on a graph of quadrature component against in-phase component) as two sets of contours representing signal variation with lift-off (for different values of stress) and signal variation with stress (for different values of lift-off), the contours of both sets being curved. The contours of one set intersect the contours of the other set at non-orthogonal angles. Surprisingly it has been found that the angles at which the constant lift-off contours intersect any one contour of constant stress are all the same. Hence measurements taken along a few contours of each set enable the positions of the other contours of each set to be determined. This method of interpreting the signals and distinguishing between stress and lift-off is described in detail in WO 03/034054.

Surprisingly this simple mapping has been found to give an accurate representation of the variation of the signals with material property (e.g. stress), and provides a simple way to distinguish these variations from variations arising from lift-off or other geometrical variations such as surface texture or curvature.

Preferably the electromagnet means comprises an electromagnetic core and two spaced apart electromagnetic poles, and the magnetic sensor is preferably arranged to sense the reluctance (or flux-linkage) of that part of the magnetic circuit between the poles of the electromagnet means. The probe, or at least some of the probes, may also include a second magnetic sensor (a flux-leakage sensor) between the poles arranged to sense magnetic flux density parallel to the free space magnetic field. This second sensor detects flux leakage, which is influenced by changes in material properties, lift-off,

and cracks.

The reluctance (or flux-linkage) signal from the or each probe is preferably backed-off, i.e. processed by first subtracting a signal equal to the signal from that sensor with the probe adjacent to a stress-free location. The backed-off signal is then amplified so the small changes due to stress are easier to detect. This backing off is performed after resolving into in-phase and quadrature components but before performing the mapping. Preferably the signals from the or each probe are digitized initially, and the backing-off and resolution are performed by analysis of the digital signals.

Whereas with the stress measurement system described in WO 03/034054 it is desirable to obtain measurements with each probe at a wide variety of different orientations, in the present context measurements at different orientations are not necessary since longitudinal loading dominates the stresses in the outer layer of the riser.

The invention will now be further and more particularly described, by way of example only, and with reference to the accompanying drawings, in which:

Figure 1 shows a perspective cut-away view of part of a riser, to show its internal structure;

Figure 2 shows an end view of a probe array for monitoring a riser as shown in figure 1, by making measurements of stress;

Figure 3 shows a longitudinal sectional view of a probe for use in the array of figure 2.

Referring to figure 1, a flexible riser 10, which acts as a hose to carry a pressurised fluid, has several concentric layers. An innermost layer 12 of helically wound bent steel strip provides resistance against external pressures, and a similar helically wound steel strip layer 14 provides hoop strength, and between these layers is a fluid barrier layer 16 of polymeric material. These are surrounded by two layers 18 and 20 of braided steel strands to provide tensile strength, separated from the steel strip layer 14 and from each other by respective anti-wear layers 17 and 19. A polymeric layer 22 provides an external sleeve and fluid barrier. As discussed above, the failure mode with such a riser 10 is typically the failure of one or more strands in the outermost braided layer 20. But it will be appreciated that these strands cannot be observed directly, because they are enclosed within the outer layer 22.

Referring now to figure 2, the stresses in the outermost braided layer 20 of a riser 10 as shown in figure 1 may be monitored using an array of electromagnetic stress-measuring probes 24 in an annular frame 25. The frame 25 is in two generally semicircular halves which are hinged together at a pivot pin 26 and locked into an annular form by a securing pin 28. Hence in use the frame 25 can be clamped so as to surround the riser 10, there being a clearance of no more than 2 mm between the inside of the frame 25 and the outer surface of the riser 10. The frame 25 is shown as carrying only six electromagnetic probes 24, although it will be appreciated that it might support a different number, and indeed it would be preferable to have the separation between adjacent probes 24 similar to the width of each probe 24. (If probes are close to each other, they should not be energized at the same time.) If greater spatial resolution is required, there may be a second such array

of probes 24 axially displaced and staggered in position relative to those shown.

Referring now to figure 3, each probe 24 includes a U-core 32 of silicon iron which defines two rectangular poles 34 in a common plane, each pole being 60 mm by 15 mm, and the space between the poles being 60 mm by 25 mm. The faces of the poles 34 are slightly curved to match the curvature of the outer surface of the riser 10. Around the upper end of the U-core 32 is a former on which are wound two superimposed coils 36 and 36a. One coil 36 has 250 turns, and in use is supplied with an AC current of 0.1 A, at a frequency of 70 Hz; this is the energising coil 36. When energized, this generates an alternating magnetic field in the U-core 32 and in the adjacent braided steel strands of the layer 20 in the riser 10, this magnetic field being small compared to the saturation field for the steel. The orientation of the probes 24 is such that the free space magnetic field is in a direction parallel to the longitudinal axis of the riser 10. The other coil 36a is a sensing coil which provides the reluctance signals.

The probes 24 may also include other magnetic sensors, for example there may be a proximity-sensing coil 40 between the poles the whose longitudinal axis is parallel to the free-space magnetic field direction, supported on a non-magnetic plate 38 fixed between the arms of the U-core. This coil 40 detects leakage flux, and is significantly affected by lift-off. The signals from the sensing coil 36a and from the leakage flux coil 40 (if provided) are amplified by a head amplifier before further processing.

In operation, with the probes 24 clamped around the riser 10, the alternating current is supplied to the

drive coils 36. The in-phase and quadrature components of the flux linkage signal (i.e. the component in phase with the drive current, and the component differing in phase by 90°) received from the sensing coil 36a are each backed off to zero, and the backing off values are then fixed. During all subsequent measurements the flux linkage components are backed off by these same amounts (i.e. subtracting a signal equal to the component observed at a stress-free location or at any rate a location of uniform stress).

The value of the stress in the layer 20 in the longitudinal direction can be determined from the experimental measurements of flux linkage, once the measurements have been compensated for lift-off. This requires calibration of the probe 24, taking measurements on a sample of material of the same type as that of the steel braid 20, while subjecting it to a variety of different stresses. This may be done with a rectangular strip sample in a test rig, flux linkage measurements being made at the centre of the sample where the principal stress direction is aligned with the axis of the test rig.

As explained in WO 03/034054, the backed-off in-phase and quadrature components of the reluctance signal from the coil 36a can be plotted on a graph. A first set of measurements are made at progressively larger values of lift-off but with no stress. This gives a changing-lift-off contour. Similar lift-off contours can be obtained for other fixed values of stress. Measurements are then made a range of different fixed values of lift-off with varying stresses (both compression and tension), providing changing-stress contours. Such a graphical display enables changes in lift-off to be distinguished from changes in stress. Such a calibration should be

carried out for at least one of the probes 24, adjacent to a sample of material of the same type as that of the steel braid 20.

After calibrating the probe 24 in this manner, measurements of stress can be readily made from observations of reluctance signals (resolved and backed off), as the contours enable the changes due to lift-off to be readily distinguished from changes due to stress. Any particular position in the impedance plane (i.e. in the graph of quadrature against in-phase components) corresponds to a particular value of stress and a particular value of lift-off. For example, by following a line parallel to a changing-lift-off contour from a particular observation, the corresponding signal values at zero lift-off can be deduced. It will be appreciated that in the present context it is unnecessary to calculate the stress in numerical terms (e.g. in MPa) as it is merely necessary to detect a position around the circumference of the riser 10 at which the measured values of longitudinal stress are significantly less than at other positions. Hence it is merely necessary to distinguish the effect of stress from the effect of lift-off: the value of stress may therefore be simply indicated by the magnitude of the reluctance signal at zero lift-off. The mapping between (in-phase, quadrature) coordinates and (stress, lift-off) coordinates may be carried out graphically, referring to such contours, or by calculation.

In some instances it may be preferable to determine the actual value of the stress, e.g in MPa, particularly where knowledge of the magnitude of the stress in relation to the yield stress of the material is required in order to evaluate the integrity of the structure. This would be the case for example with a wire rope, if the

risk of breaking is to be assessed.

Claims

1. A method for monitoring a flexible elongate structure comprising at least one layer of steel wires near the surface, the steel wires extending at least partly along the length of the structure, the method comprising inducing an alternating magnetic field much less than saturation in the steel wires using an electromagnetic coil, and monitoring the alternating magnetic flux density near the surface of the structure, determining from it a parameter indicative of stress in the steel wires, and hence detecting if any wires have broken.

2. A method as claimed in claim 1 wherein the magnetic field is in a direction substantially parallel to the longitudinal axis of the structure.

3. A method as claimed in claim 1 or claim 2 comprising the steps of arranging an array of electromagnetic stress sensing probes around the circumference of the elongate structure, and detecting a variation of the measured stress around the circumference.

4. A method as claimed in any claim 1 or claim 2 wherein a single coil is arranged to encircle the elongate structure, so that changes in stress in all the reinforcing wires are monitored simultaneously.

5. A method as claimed in claim 3 wherein each probe comprises an electromagnet means, means to generate an alternating magnetic field in the electromagnet means and consequently in the structure, and a magnetic sensor arranged to sense a magnetic field due to the electromagnet means; and the method comprises resolving signals from the magnetic sensor into an in-phase component and a quadrature component; and mapping the in-

phase and quadrature components to distinguish between changes in lift-off and changes in stress.

6. An apparatus for monitoring a flexible elongate structure by a method as claimed in any one of the preceding claims.

15786 MdCm

P T Mansfield
Chartered Patent Agent
Agent for the Applicant

Abstract

Detecting Failures in Flexible Multistrand Steel Structures

A flexible elongate structure, such as a flexible riser (10), comprising at least one layer (20) of steel wires near the surface which extend at least partly along the length of the structure, can be monitored by inducing a small, alternating magnetic field in the steel wires using an electromagnetic coil, and monitoring the magnetic flux density near the surface of the structure so as to assess the stress and hence detect if any wires have broken. By using an array of stress-measuring electromagnetic probes (24) around the structure some spatial resolution can be provided as to the location of any break in the wires.